

California Demonstration Energy Efficiency-Indoor Environmental Quality Project: Predicted Relocatable Classroom Indoor Air Quality due to Low-Emitting Interior Materials and Enhanced Ventilation

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Supported by the California Energy Commission

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Improving IEQ in Relocatable Classrooms

LBNL – Davis Energy Group

Supported by the California Energy Commission

- **Goals:** In relocatable classrooms (RCs), quantify and demonstrate benefits of technologies that simultaneously save energy and improve indoor environmental quality (IEQ).
- **Problem:** Opportunities for simultaneous energy and IEQ benefits not adequately recognized or quantified.
- **Anticipated Long-Term Benefits**
 - Exposure reduction, Energy savings, & Improved health and learning



RCs at Rose Avenue Elementary School

Improving IEQ in Relocatable Classrooms (RCs)

Collaborators: LBNL – Davis Energy Group –American Modular Systems (AMS) –
Cupertino Unified and Modesto City School Districts

Tasks

- **Energy and IAQ Field Studies in 4 new RCs**
 - Quantify energy and IEQ performance of indirect/direct evaporative cooling (IDEC) performance vs. standard system
 - Improve input data for models of RC performance
 - Work with RC manufacturer(s) to implement practical volatile organic compound (VOC) source control strategies.
- **Energy Simulation and State-Wide Energy Savings**
 - DOE-2 modeling and energy/cost-benefit analyses for California climates



Status

- RCs constructed & installed, 8 weeks of cooling season data collected.

VOC Source Control Strategies

TASKS

- ❑ Evaluate interior finish materials for RCs for VOC and aldehyde sources.
- ❑ Characterize the current sources of VOCs of concern with respect to health and comfort
- ❑ Identify practical procedures for reducing classroom concentrations of these compounds, i.e., substitution
- ❑ Select suitable alternate materials for construction of two experimental RCs
- ❑ Monitor VOCs and aldehyde concentrations and source strengths in standard and experimental RCs

Study Design

- ❑ Two RCs each in Two Schools:
 - 1 in extreme climate (MCS)
 - 1 in moderate climate (CUSD)
- ❑ Each School has:
 - 1 RC w/standard materials
 - 1 RC w/selected low VOC materials
- ❑ Each RC has **two** HVAC systems
 - BARD - standard heat pump (0-15 CFM/person)
 - IDEC - low energy (continuous 15 CFM/person)



IDEC and Standard HVAC at
Stevens Creek Elementary School

Materials and Methods

- ❑ Selected Mfr.: American Modular Systems (AMS)
- ❑ AMS provided standard RC interior material samples
- ❑ Standard materials differed slightly in CUSD and MCS designs
- ❑ Potential alternate low-VOC emitting material samples collected from building industry sources.



- ❑ Materials prepared in laboratory for standard testing procedure
- ❑ Conditioned in 19 L chambers for 10dy
- ❑ VOC & aldehyde samples collected in 10L chambers for 96h
- ❑ GCMS & HPLC Analyses

Criteria for Alternative Material Selection

Parameter	Evaluation Procedure
Chemicals of concern and odorous compounds	Estimate concentrations for ventilated and closed conditions using emission factors and classroom parameters
Compounds with RELs [*]	Compare estimated concentrations with guideline values
Odorous compounds	Compare estimated concentrations with odor thresholds
Material performance	Consider appearance, durability, maintenance requirements, sound properties, etc.
Cost	Compare material and installed costs of standard and alternate materials
Acceptability	School districts and manufacturer can reject recommended alternate materials

^{*}RELs = Reference Exposure Levels

Tested Standard and Alternate Materials

Material Description	Code*	Class
Carpet		
Olefin fiber broadloom carpet bonded to plywood w/solvent-free full-spread adhesive	BLC1-s	Std
Nylon 6,6 fiber broadloom carpet bonded to plywood w/solvent-free full-spread adhesive	BLC2	Alt
Nylon 6 fiber broadloom carpet bonded to plywood w/adhesive tape	BLC3	Alt
Nylon 6,6 fiber broadloom carpet bonded to plywood w/adhesive tape	BLC4	Alt
Nylon 6,6 fiber olefin hardback carpet	HBC	Alt
Nylon 6,6 fiber closed cell vinyl cushion carpet	VCC	Alt
Resilient Flooring		
Sheet vinyl flooring	SVF-s	Std
Vinyl composition floor tile	VCT-s	Std
Resilient floor tile, chlorine-free	RFT	Alt
Tackable Wall Panel		
Vinyl covered fiberboard wall panel	VWP1-s	Std
Teflon-coated vinyl covered fiberboard wall panel	VWP2	Alt
Vinyl covered mineral fiber wall panel	VWP3	Alt
Fabric covered mineral fiber wall panel	FWP1	Alt
Fabric covered recycled paperboard wall panel	FWP2	Alt
Ceiling Panel		
Fiberglass ceiling panel	FCP-s	Std
Mineral fiber ceiling panel w/anti-microbial agent	MCP1	Alt
Mineral fiber ceiling panel	MCP2	Alt

Materials Selection - VOC Criteria

Criteria	Date
Air Toxics Hot Spots Program Risk Assessment Guidelines; Chemicals with Established Noncancer Chronic Reference Exposure Levels (RELs); Calif. EPA, Office of Environmental Health Hazard Assessment	May 2000
Substances Identified as Toxic Air Contaminants (TACs, includes all Hazardous Air Pollutants listed in the Federal Clean Air Act Amendments of 1990); Calif. EPA, Air Resources Board	Mar. 2001
Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65); Chemicals Known to the State to Cause Cancer or Reproductive Toxicity; Calif. EPA, Office of Environmental Health Hazard Assessment	Feb. 2001
Potential odor effect. from standardized human olfactory thresholds (Devos <i>et al.</i> , 1990).	1990

Number of Compounds Identified in Materials by Chemical Class: Carpet and Flooring

Chemical Class	Number of Compounds								
	BLC1-s	BLC2	BLC3	BLC4	HBC	VCC	VCT-s	SVF-s	RFT
Aldehyde	3	8	8	7	1	2		1	1
Ketone	1	2	1	1	1				
Carboxylic acid		1	1	1	1	2			
Alcohol	5	5	5	4	1	2	2	2	
Glycol ether		1	3	3			1		
Acetate and ester	2	1	2	3		1		2	1
Chlorinated cpd.	1	1							
Aromatic HC ^a	4	7	1	1	6			19	1
Terpene HC	10	8	1	1					
Alkene HC						1			
Cyclic HC	5	3							
Alkane HC	4	5	2	2				4	1
Nitrogen compound	1		2	1	1	1			
Unidentified cpd.				3		2	1	10	
Total Number	36	42	26	27	11	11	4	42	4

Note: s designation = standard material

Number of Compounds Identified in Materials by Chemical Class: Wall and Ceiling Panels

	Number of Compounds							
Chemical Class	VWP1-s	VWP2	VWP3	FWP1	FWP2	FCP-s	MCP1	MCP2
Aldehyde	2	2	4	5	9	1	2	1
Ketone					1			
Carboxylic acid	1		2	1	5			
Alcohol	3	1	1	1		1		
Glycol ether	1		1	2	1		2	
Acetate and ester	1	3			1		1	1
Chlorinated Cpd.				1				
Aromatic HC ^a	9	1	12	4				
Terpene HC							1	
Cyclic HC	3		3					
Alkane HC	8	2	2		1			
Nitrogen compound	1						1	
Silicone compound	1							
Unidentified Cpd.						1		1
Total Number	30	9	25	14	18	3	7	3

Note: s designation = standard material

Final Study RC Material Selections

Standard RC

Experimental RC

Floor Covering

Olefin fiber broadloom carpet bonded to plywood with solvent-free full-spread adhesive (MCS)

Nylon 6,6 fiber, olefin hardback carpet bonded to plywood with adhesive tape (MCS)

Nylon 6,6 fiber broadloom carpet bonded to plywood with solvent-free full-spread adhesive (CUSD)

Vinyl composition floor tiles (MCS)

Sheet vinyl flooring (CUSD)

Walls (CUSD & MCS)

Vinyl covered fiberboard wall panels

Teflon-coated vinyl covered fiberboard wall panels

Ceiling (CUSD & MCS)

Fiberglass ceiling panels

Mineral fiber ceiling panels

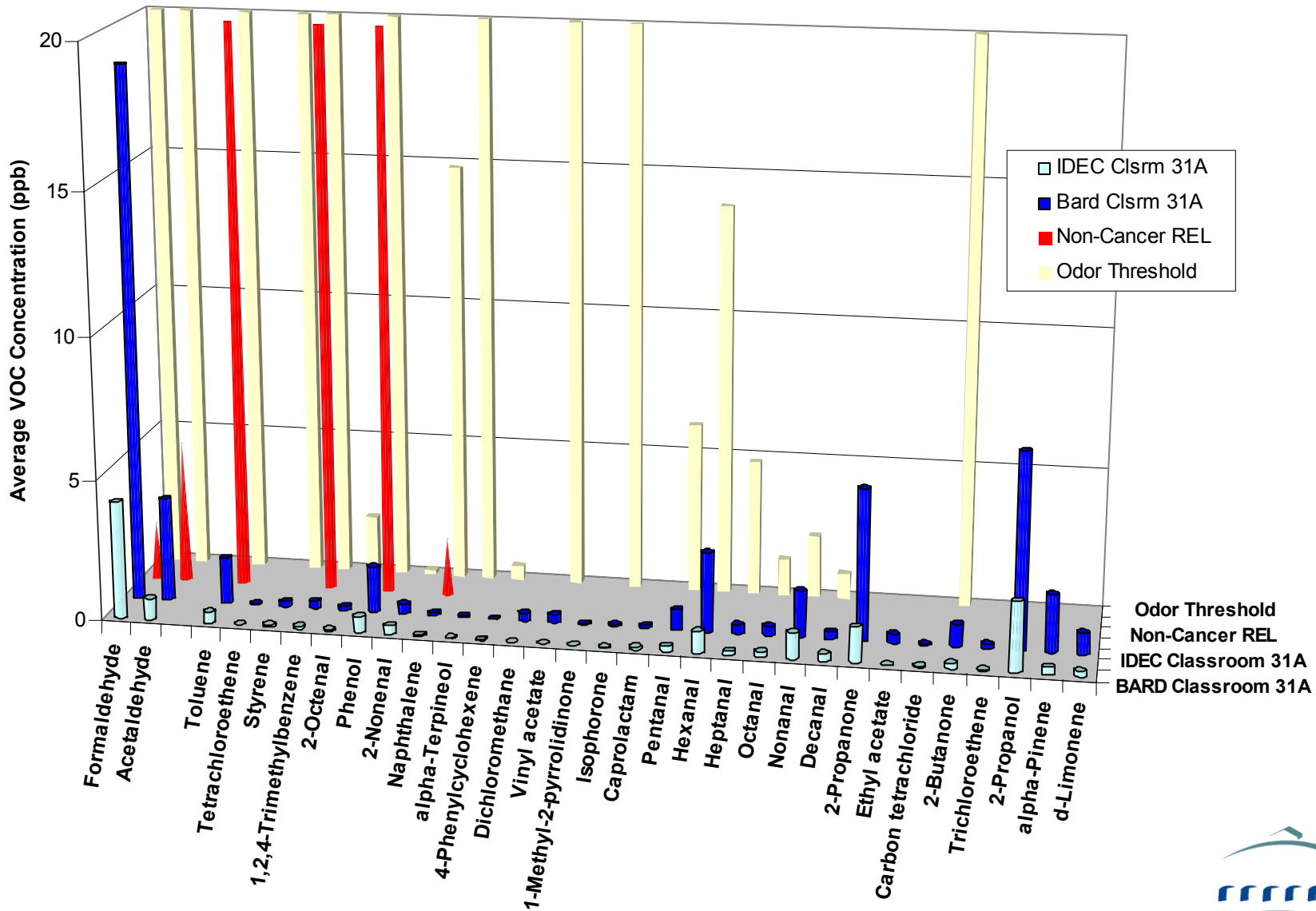
Predicted VOC Concentrations CUSD

Compound	REL ^d ppb	Predicted Concentration, ppb				RC 1c Identified Sources ^e	RC 2 Identified Sources
		RC 1c	RC 2				
		@ 680 m ³ h ⁻¹	@ 33 m ³ h ⁻¹	@ 535 m ³ h ⁻¹	@ 33 m ³ h ⁻¹		
Formaldehyde	2	3.3	67.1	--	--	CP	
Acetaldehyde	5	5.0	103	4.1	66.7	C, SVF, WP	C, SVF, WP
2-Butanone		0.1	2.5	0.2	2.5	C	C
Phenol	50	3.6	74.5	1.8	28.6	SVF, WP, CP	SVF, WP
DEGBE ^a		1.1	23.1	0.1	2.0	C, WP	C
Vinyl acetate		32.4	668	14.4	233	WP	WP
Tetrachloroethene		<0.1	0.5	<0.1	0.5	C	C
Toluene	70	--	--	0.9	15.1		WP
1,2,4-TMB ^b		0.4	7.8	0.1	2.1	SVF, WP	SVF
Naphthalene	2	0.1	1.4	0.1	1.4	C	C
1-Methyl-2-pyrrolidinone		5.3	109	--	--	WP	

Predicted VOC Concentrations MCS

Compound	REL ^d ppb	Predicted Concentration, ppb				RC 3c Identified Sources ^e	RC 4 Identified Sources
		RC 3c @ 535 m ³ h ⁻¹	@ 33 m ³ h ⁻¹	RC4 @ 535 m ³ h ⁻¹	@ 33 m ³ h ⁻¹		
Formaldehyde	2	4.1	67.1	<1	8.1	CP	C
Acetaldehyde	5	4.4	71.9	2.2	35.4	WP	WP
Isophorone		--	--	<0.1	0.7		C
Phenol	50	3.1	50.3	0.3	4.4	WP, CP	WP
DEGBE ^a		1.3	21.2	<0.1	0.1	VCT, WP	VCT
Vinyl acetate		41.2	668	14.4	233	WP	WP
Toluene	70	--	--	0.9	15.1		WP
Styrene	200	0.1	1.0	--	--	C	
1,2,4-TMB ^b		0.4	5.7	--	--	WP	
1-Methyl-2-pyrrolidinone		6.9	111	--	--	C, WP	
Caprolactam		--	--	0.3	4.6		C

VOC Results: CUSD RC-A IDEC vs. Bard



VOC Results: MCS RC-A vs. RC-B IDEC

